

Deposition of Carbonous Nanotips on Field Emitters

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It is well known, that for efficient field emission electric fields in the range of 10^8 V/m are required. The reduction of the tip radius of the emitter shows a strong effect on electron emission, by field enhancement. Sharp tip radii can be achieved directly by the fabrication of the emitter. In this case the emitter suffer from a limited accuracy of fabrication processes and therefore large deviation of the single devices. Furthermore, degradation processes during operation lead to terminal decrease of the emission performance. Searching for a new way to sharpen emitter tips during operation, tungsten and silicon tips were exposed to methane gas during emission to create ultrafine carbon tips. These tips are consequently sharper than the base material and thus achieved higher emission currents. This grown tips were investigated regarding their operational robustness and regarding a possible recoverability of the carbon tips post degradation. Different growth steps were documented via SEM.

1. MOTIVATION

In literature, different groups like NAKAHARA [1] and YEONG [2] investigated growth of carbon on tungsten and other metal field emitters (FE). For our experiments we tried to reproduce those experiments and also achieve carbonous nanotips on silicon emitters.

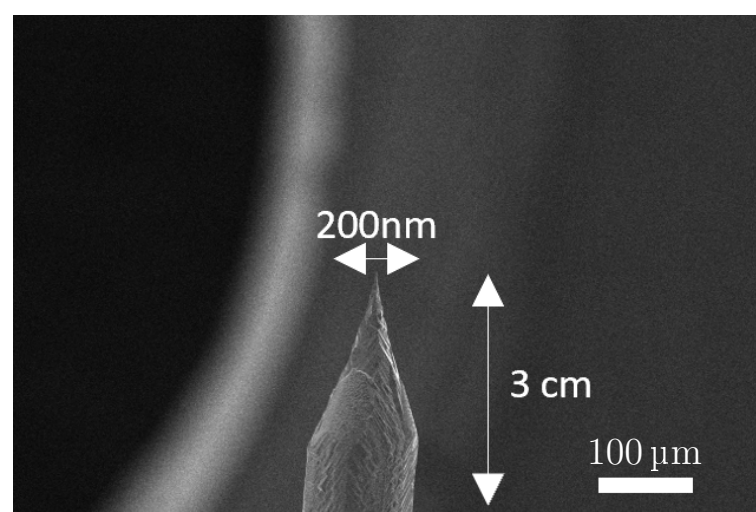
Advantages of in situ growth of carbon Nanotips

- grown tips are sharper and therefore, increase emission current
- resharpening of degraded emitter, in order to recover performance
- easy and reproducible recovery of devices during operation

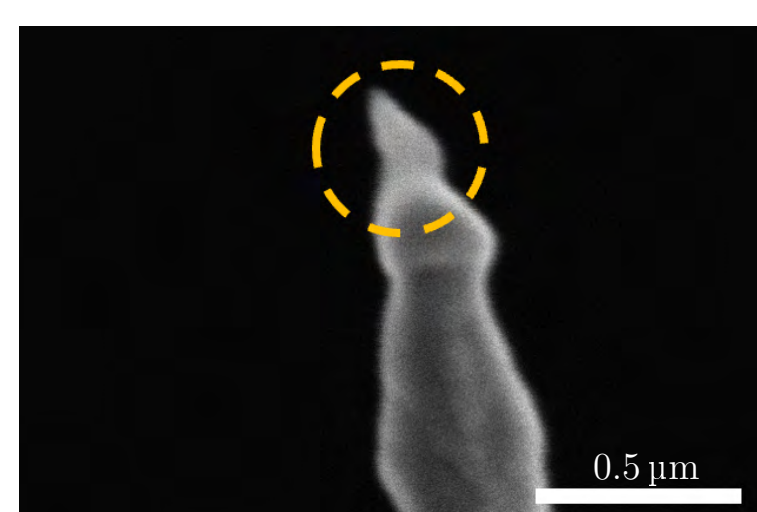
In order to improve the FE behaviour, methane gas was introduced into the vacuum chamber during operation of the field emitter tips. This leads to formation of small carbonous tips as visible in (Fig. 1b) and (Fig. 1d).

Tip sizes before and after carbon deposition

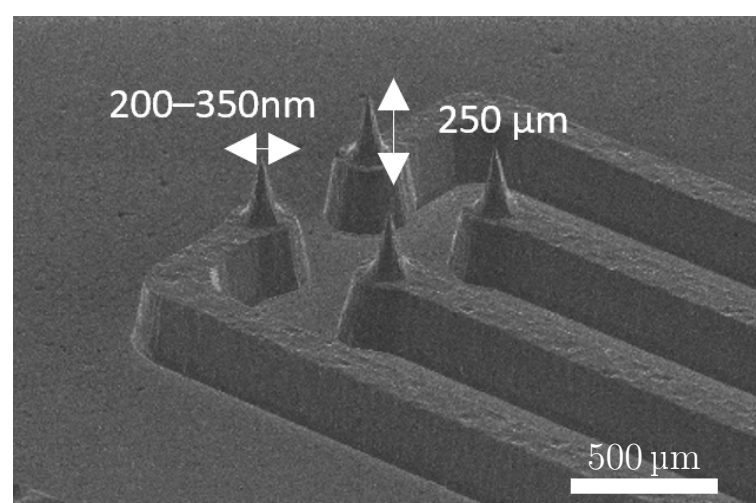
figure	type	process step	tip radius	grown tip height
Fig. 1a	tungsten	pre methane	200 nm	
Fig. 1b	tungsten	post methane	<50 nm	0.24 μ m
Fig. 1c	silicon	pre methane	200 to 350 nm	
Fig. 1d	silicon	post methane	<75 nm	0.3 μ m



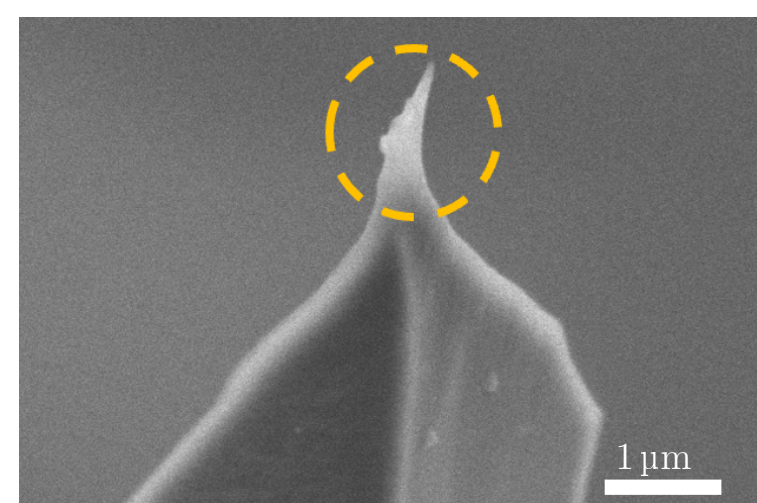
(a) single tip tungsten FE



(b) tungsten FE with carbon tip



(c) four-tip silicon FE



(d) silicon FE with carbon tip

Figure 1: SEM images of tungsten (a, b) and silicon FE (c, d) before and after carbonous nanotips were grown, the orange circles highlight the grown carbon.

2. FABRICATION PROCESS

During the experiments two different field emitter materials were used. Tungsten emitters were produced by using about 3 cm long tungsten needles, which were electrochemically etched in an NaOH solution until a tip diameter of about 200 nm was formed. The silicon emitters are fabricated by laser micromachining as described in [3] using phosphorous-doped silicon with resulting resistivities of about $0.005 \Omega/\text{m}$. The main steps of the fabrication are shown in Fig. 2.

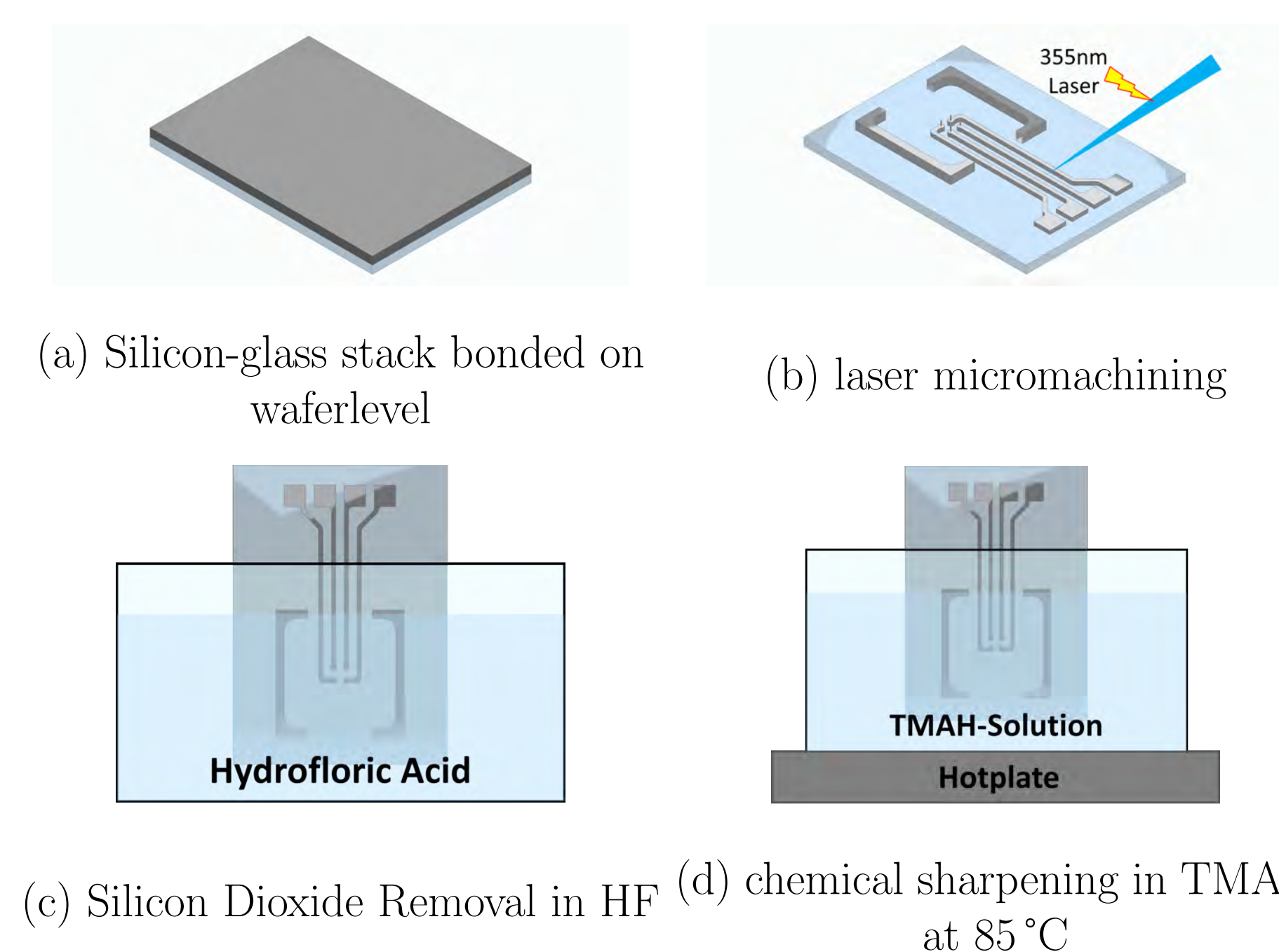
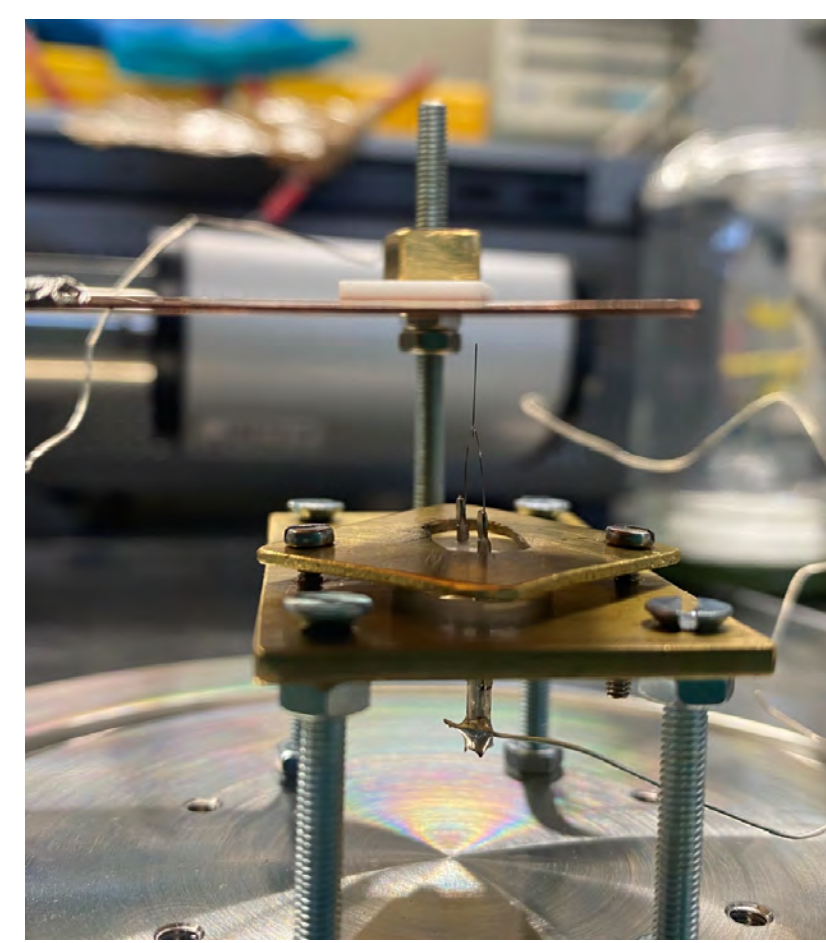


Figure 2: Schematic of Silicon Field Emitter Production via Laser micromachining.

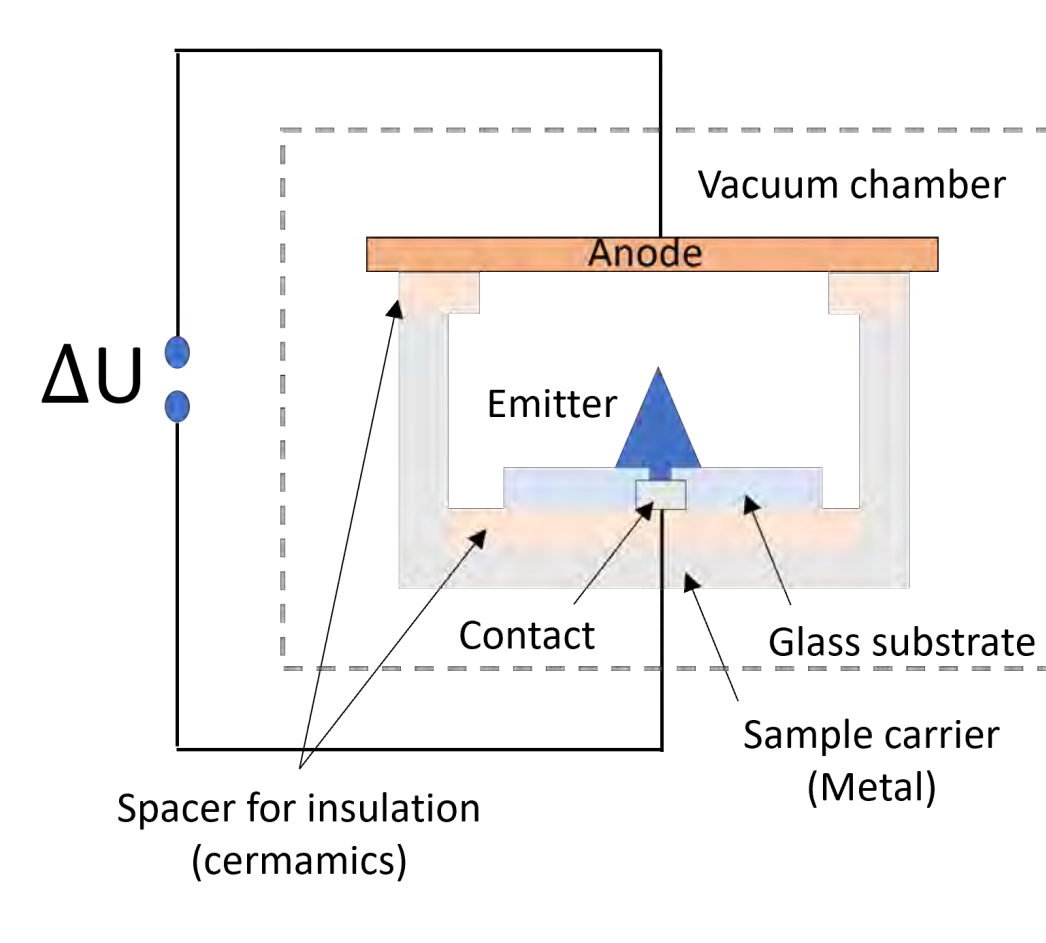
3. MEASUREMENT SETUP

Main components in the deposition setup:

- ORTEC/AMETEK Model 660 Dual 5 kV Radiation Detector Bias Supply (Voltage Supply)
- Tektronix 6517B Electrometer (emission current detection)
- Vacuum chamber system with base pressure $p_0 = 10^{-7}$ mbar
- modular sample holder adjustable for tungsten or silicon field emitter devices (Fig. 3a,b)



(a) tungsten emitter in setup



(b) schematic experimental arrangement

Figure 3: Image of the vacuum chamber interior with tungsten emitter arrangement (a) and a schematic of over all setup (b).

4. EXPERIMENTAL EXECUTION

Main parameters for the tip growth experimnts to adjust were acceleration voltage, methane pressure, and deposition time. The tungsten emitters were tested at voltages ranging from 1.7 to 2.3 kV, methane at $p_{\text{methane}} = 5 \cdot 10^{-5}$ to $1 \cdot 10^{-4}$ mbar and a growth time between 7 and 20 minutes. The silicon emitters were treated between 7 and 20 minutes, as well. Silicon was tested using 1.6 up to 2.5 kV and methane pressures from 10^{-4} to $1 \cdot 10^{-2}$ mbar.

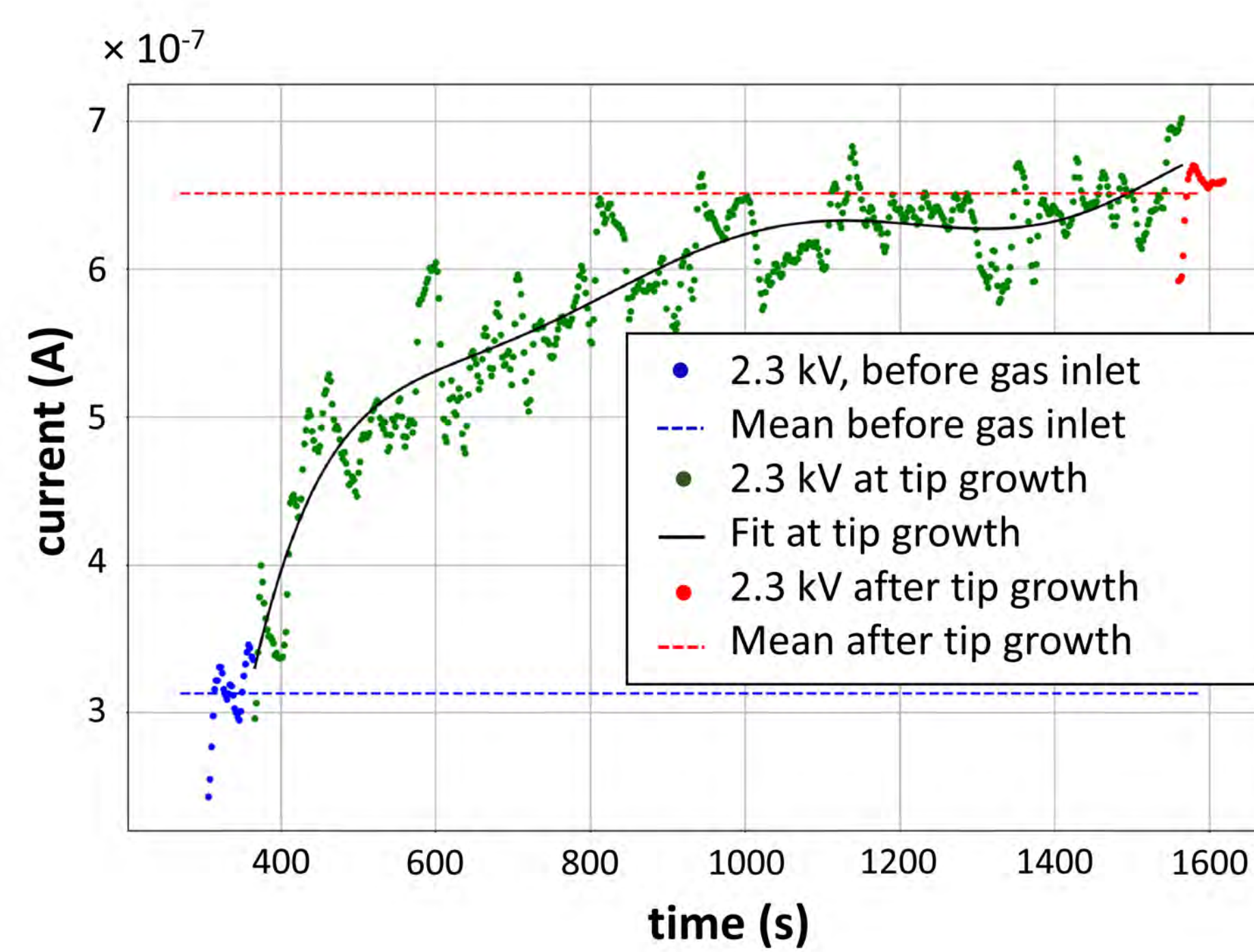


Figure 4: Emission current during experiment on a tungsten FE at 2.3 kV extraction voltage in three sections: blue section: emission of bare device before methane exposure, green section: emission current during methane presence ($p_{\text{methane}} = 5 \cdot 10^{-5}$ mbar), red section: emissin current after methane is removed.

Results

type	tip size l_{max}	current I_{max}	Δ emission ΔI_{max}
tungsten	0.81 μ m	919 nA(2.3kV)	609 nA(2.3kV)
silicon	5 μ m	800 nA(2.1kV)	~ 700 nA(2.1kV)

Note: Maximum tip growth and maximum emission were not observed in the same emitters, suggesting that other geometric factors have a stronger impact than the length of the carbonous tip.

5. REPEATABILITY TESTS

For technical application of the in situ grown carbon nanotips, it is further of high interest if the deposition on the emitter tips is reproducible. Therefore, the experiment was executed and carried on under harsh conditions at an acceleration voltage of 3.1 kV until the carbonous tips degraded. Afterwards, the system was set under methane atmosphere again. The experiment was repeated three times (Fig. 5).

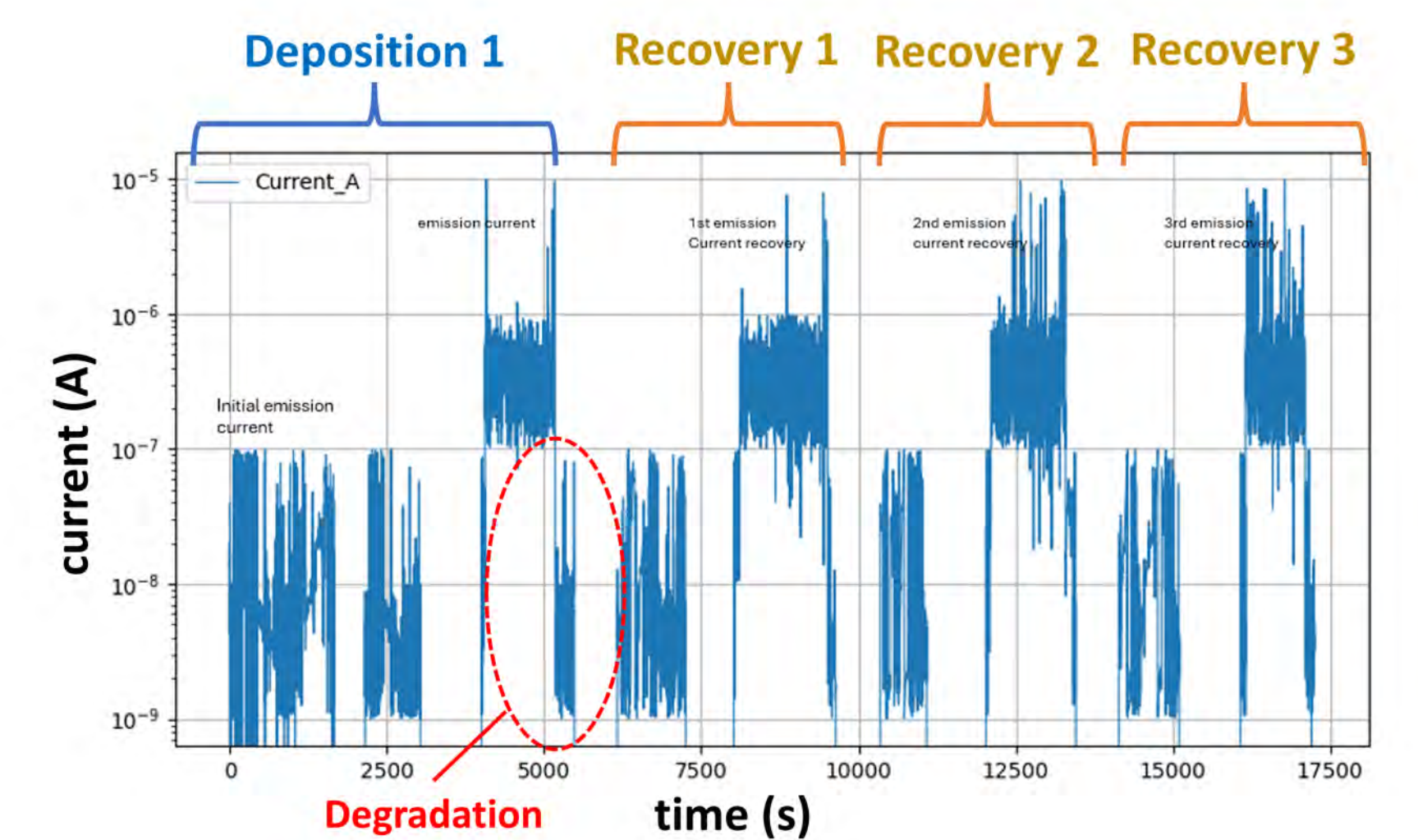


Figure 5: Recoverability test on a silicon FE tip, acceleration voltage is set on 3.1 kV, growth conditions were set to $p_{\text{methane}} = 10^{-4}$ mbar for 15 min. Harsh voltage conditions led to a quick degradation of the carbon tip (red circle). Repeating the experiment (orange brackets) could recover the higher emission level three times.

The experiment clearly demonstrated that the carbon tips can be restored by intentionally introducing methane gas into the system. This experiment was successful for both the tungsten and silicon tips.

6. CONCLUSION AND OUTLOOK

Conclusion

- carbonous nanotips as reported on metal FE could also be deposited on silicon FE devices
- the deposited heteromaterial led into an improved pervormance of the device
- carbon nanotips on silicon showed less stable behaviour than on tungsten
- on both emitter materials degraded emitter tips were recoverable

Outlook

- adjustment of grow conditions on best possible reproducibility and emitter performance
- transfer of deposition technique to more efficient FE-designs as described at BUCHNER [4]
- technical application of FE sharpening during emission

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